

TESTING QUASI-DIRAC LEPTOGENESIS THROUGH OSCILLATIONS

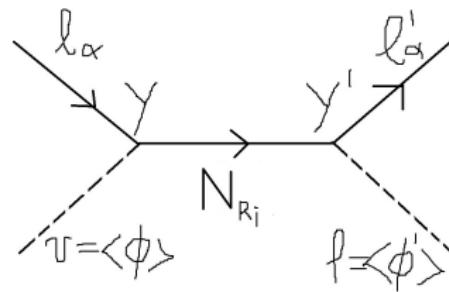
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Snowmass 2021, NF03 Kick-off day 2

October 1, 2020

Dirac see-saw model [C.-S. Fong, T. Gregoire, AT arXiv:1903.12192]

- Neutrino masses generated through **L-conserving** Dirac see-saw



- Heavy neutral leptons N_R + light R-handed neutrinos $\nu_R = (\nu'_L)^c$ + new singlet scalar Φ' (inspired by Mirror world models)

$$\mathcal{M}_\nu \simeq -v f Y M^{-1} Y'^T$$

- Successful leptogenesis $M_1 > 10^9$ GeV

Quasi-Dirac model [C.-S. Fong, T. Gregoire, AT

arXiv:2007.09158]

- L-conserving lagrangian ($\alpha = 1, 2, 3 \quad i, j = 1, \dots N_f$)

$$\begin{aligned}\mathcal{L} = & i\bar{N}_{Ri}\not{\partial}N_{Ri} + i\bar{N}'_{Ri}\not{\partial}N'_{Ri} - \textcolor{blue}{M}_i\bar{N}_{Ri}N'^c_{Ri} + \text{h.c.} \\ & - \textcolor{blue}{y}_{\alpha j}\bar{l}_{L\alpha}\tilde{\Phi}N_{Rj} - \textcolor{blue}{y}'_{\alpha j}\bar{l}'_{L\alpha}\tilde{\Phi}'N'_{Rj} + \text{h.c.}\end{aligned}$$

- L-violating lagrangian

$$\begin{aligned}\mathcal{L} = & -\frac{1}{2}\textcolor{red}{m}_{ij}\bar{N}^c_{Ri}N_{Rj} - \frac{1}{2}\textcolor{red}{m}'_{ij}\bar{N}'^c_{Ri}N'_{Rj} \\ & - \tilde{y}_{\alpha i}\bar{l}_{L\alpha}\tilde{\Phi}N'_{Ri} - \tilde{y}'_{\alpha i}\bar{l}'_{L\alpha}\tilde{\Phi}'N_{Ri} + \text{h.c.}\end{aligned}$$

- Assume $m = m'$, $y = y'$ and $\tilde{y} = \tilde{y}'$ and small L-violating terms

$$|m| \ll M \quad |\tilde{y}| \ll |y|$$

Neutrino masses

- Realistic model requires $N_f \geq 2$. We have

$$\mathcal{M}_\nu \simeq -v^2 Y \mathcal{M}^{-1} Y^T$$

where

$$Y = \begin{pmatrix} y & \tilde{y} \\ \tilde{y} & y \end{pmatrix} \quad \mathcal{M} = \begin{pmatrix} m & M \\ M^T & m \end{pmatrix}$$

- Diagonalization

$$\begin{pmatrix} \nu_{L\alpha} \\ \nu'_{L\alpha} \end{pmatrix} = \boldsymbol{\Omega}_{\alpha i} \nu_i \quad \boldsymbol{\Omega} = \begin{pmatrix} \Omega_{3 \times 6}^A \\ \Omega_{3 \times 6}^S \end{pmatrix}$$

where $\boldsymbol{\Omega}$ is a 6×6 unitary matrix such that

$$\boldsymbol{\Omega}^\dagger \mathcal{M}_\nu \boldsymbol{\Omega}^* = \text{diag}(m_{1+}, m_{1-}, m_{2+}, m_{2-}, m_{3+}, m_{3-})$$

- Pseudo-Dirac pairs

$$m_{i\pm} = \textcolor{blue}{m}_i \pm \textcolor{red}{\delta m}_i \quad \textcolor{red}{\delta m}_i \ll \textcolor{blue}{m}_i$$

$N_f = 1$ leptogenesis

- Heavy singlet fermions split into quasi-Dirac pair N_{\pm}

$$M_{\pm} \simeq \textcolor{blue}{M} \pm \frac{|\textcolor{red}{m'} + m^*|}{2}$$

- CP violating decays ($N_{\pm} \rightarrow l_{\alpha}\Phi, \bar{l}_{\alpha}\bar{\Phi}$)

$$\epsilon = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}} \quad \lesssim \quad \frac{\tilde{y}}{y}$$

- Baryon asymmetry

$$n_B \propto \epsilon$$

- Maximal value for $\Delta M \simeq \Gamma$ (resonant enhancement)

$$|\epsilon^{\max}| \quad \simeq \quad \frac{\tilde{y}}{\textcolor{blue}{y}}$$

$N_f = 1$ neutrino masses

Two massive light neutrinos also split into quasi-Dirac pair

$$m_{\mp} = m_\nu \mp \delta m$$

where

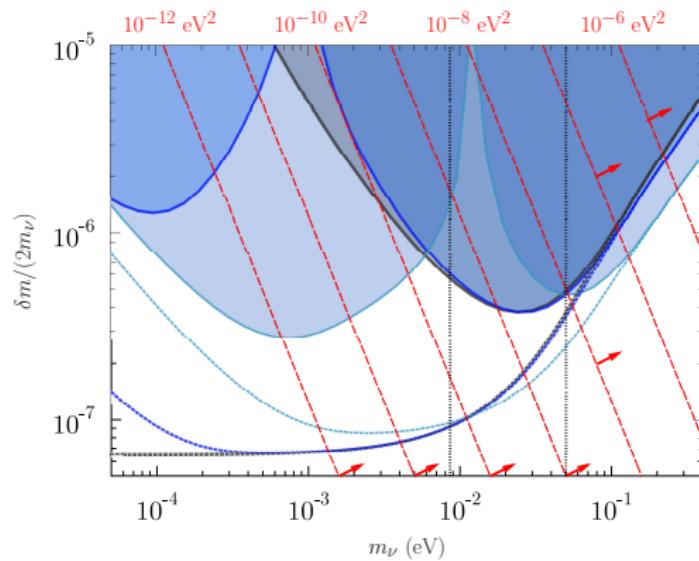
$$m_\nu \equiv \frac{y^2 v^2}{M} \quad \delta m \simeq 2|\tilde{y}y|v^2/M$$

Intriguing relation between the CP parameter and neutrino mass splitting

$$|\epsilon^{\max}| \simeq \frac{\delta m}{2m_\nu}$$

Results [arXiv:2007.09158]

Regions of sufficient baryon asymmetry



$M \gg 1 \text{ TeV}$ (gray), $M = 1 \text{ TeV}$ (blue) and $M = 500 \text{ GeV}$ (light blue) for zero (solid) and thermal (short dashed) initial N_i abundance.

Proposed study

- Explore the full parameter space

$$(M, m, y, \tilde{y})$$

for $N_f = 2$ and $N_f = 3$ taking into account leptogenesis, neutrino masses and oscillation constraints

- $N_{2\pm}$ and $N_{3\pm}$ leptogenesis
- Oscillations depend on δm_i and Ω^A

$$\Omega^A = \frac{1}{\sqrt{2}} \begin{pmatrix} A(U_{PMNS} + B) & iA(U_{PMNS} - B) \end{pmatrix}$$

A, B depend on additional 9 angles and 9 phases

- ...

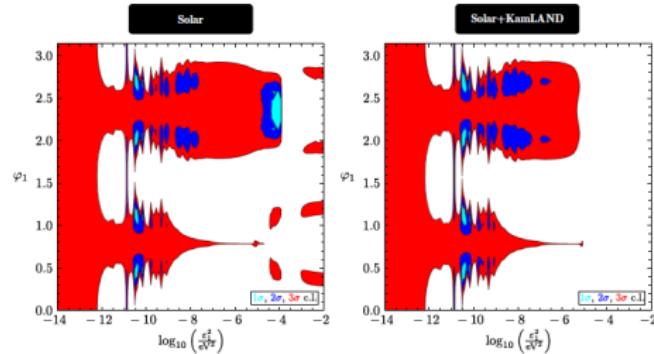
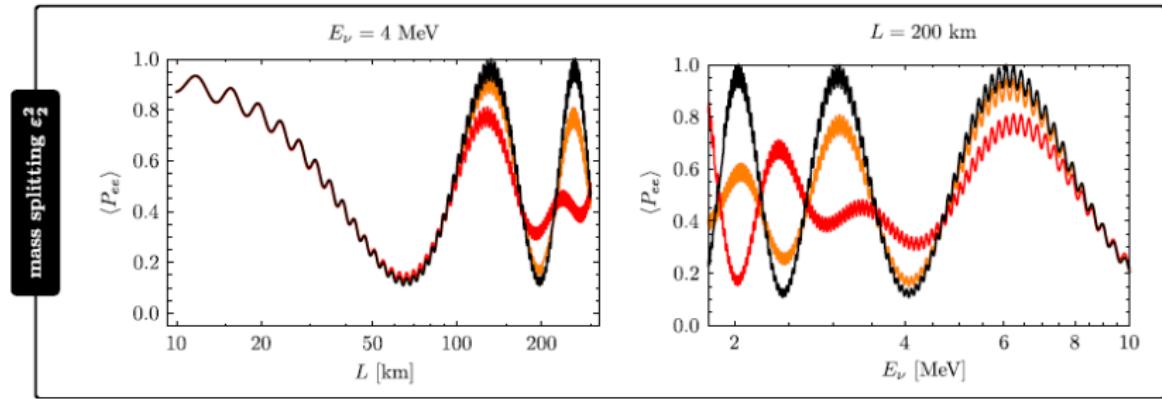


Thank you

BACK UP

Quasi-Dirac oscillations fit and constraints

- Phenomenological study [Anamiati, Fonseca, Hirsch 1710.06249]



Phenomenology

- LFV can be induced at one-loop level through loop of heavy quasi-Dirac fermions N

$$\text{Br}(\mu \rightarrow e\gamma) \approx 6 \times 10^{-26} \left(\frac{m_\nu}{0.1 \text{ eV}} \right)^2 \left(\frac{500 \text{ GeV}}{M} \right)^2$$

- Current experimental bound

$$\text{Br}(\mu \rightarrow e\gamma) < 4.2 \times 10^{-13}$$

- Neutrinoless beta decay rate is prop to

$$(M_\nu)_{ee} \simeq -\frac{2y_e \tilde{y}_e v^2}{M}$$

suppressed by $\tilde{y}_e \ll y_e$, not likely to be measured even in the next generation experiments which aim to probe $(M_\nu)_{ee} \sim 10 \text{ meV}$